Application of Earth Sciences Products for use in Next Generation Numerical Aerosol Prediction Models

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LONG-TERM GOALS

In this project we rapidly devise a forward modeling system to characterize and predict clear sky radiation fields through the harvest of a number of preexisting basic research programs funded by Navy and other government agencies (NASA, NOAA, DOE, etc.). By combining prognostic aerosol and meteorological fields from the NRL Aerosol Analysis and Prediction System (NAAPS) and Coupled Ocean Atmosphere Mesoscale Prediction System (COAMPS®) with near real time satellite surface and aerosol products via a high resolution radiative transfer model, angular clear sky radiance fields and diabatic heating rates can be generated and predicted. Through this system, we will be able to advance a number of US Navy Applied Science needs in the areas of improved Electro Optical (EO) propagation prediction and aerosol meteorology interaction. Particular focus of these subject areas surrounds the further development of the Navy's atmospheric constituent data assimilation system, including the utilization of a number of satellite based products. Deliverables surround a system for the calculation of atmospheric radiance fields from Navy data feeds. From this project we will deliver quasi-operational computations of aerosol impacts on atmospheric diabatic heating rates and surface fluxes, as well as a significant upgrade to the US Navy's aerosol data assimilation system through the inclusion of a number of additional satellite sensors. With this enhanced capability we will be able to significantly improve source functions for Navy aerosol models, as well as prepare for expected data gaps in the early 2010's.

OBJECTIVES

Scientific objectives of this project are tightly aligned with the long term goals listed above, and can be broken down into the following categories in order of relative project order a) model data assimilation and initialization; b) source functions; c) radiative transfer; d) synthesis and scale independent integration. In this first year of the project, focus has surrounded the transition of data assimilation and its use for improving source functions. Specific objectives are as follows:

Validate the new operational collection 5 over water MODIS aerosol product for replacement of collection 4 currently used in operational data streams.

Develop quality assurance and quality control procedures for over land MODIS aerosol product and expand assimilation to all traditional dark target surfaces. This includes the evaluation of the current state of satellite aerosol measurement over land relative to the accuracy requirements of the Navy Aerosol Analysis and Prediction System.

Perform a multi-year aerosol data assimilation test analysis using the newly developed quality assured MODIS over water and over land aerosol products.

Develop a 3-D aerosol climatology using multi-year Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) data. Apply the developed climatology to previous data assimilation efforts.

Based on the assimilation based NAAPS analysis, improve the smoke aerosol source descriptions and model used operationally by the Navy.

Stage the Bond et al., (2004) source function for non-biomass organic and black carbon for use in the Navy Aerosol Analysis and Precition System (NAAPS).

APPROACH

Much of the work performed this year surrounds the development of appropriate error matrices for the satellite products to be assimilated. High-precision aerosol measurements from the global AERONET monitoring network were used to perform a detailed evaluation of the MODIS version 5 aerosol optical depth retrieval over land areas. Where necessary, additional ancillary observations such as global albedo and snow cover data sets were used to enhance the analysis. After identifying and quantifying uncertainties in retrieved AOD, empirical corrections and bad data screening. A final quality assurance system for MODIS AOD observations generates an aggregated observation field with well-defined uncertainty for use in data assimilation applications.

Once a suitable product is available, it can be assimilated into the model. An aerosol optical depth data assimilation system has been developed at NRL that incorporates aerosol optical depth retrievals into the NRL Atmospheric Variation Data Assimilation System (NAVDAS). NAVDAS has been operational since October 1, 2003 for NOGAPS, and will become operational for COAMPS® in the near future. NAVDAS is capable of assimilating conventional observations, univariate observations (such as moisture and ozone), and observations with complex nonlinear observation operators (such as satellite radiances and the Special Sensor Microwave Imager wind speed). The MMD has completed the use of the univariate two-dimensional capabilities of NAVDAS for MODIS level 2 optical depth assimilation into NAAPS. When more products become available, through geostationary satellite imagers or other polar orbiters such as the European MetOP, they too can be added to the analysis.

As components of the satellite products/assimilation system are completed, we can begin the feedback process on improving source functions. Because the assimilation process requires a reasonable first guess by the model, several iterations between model analysis and observations over large time series are required to optimize the system.

WORK COMPLETED

Because NASA MODIS standard optical depth data as undergone a new version release, a rapid analysis of product efficacy was undertaken. Validated the collection 5 MODIS over water aerosol product was performed using three years of MODIS and AEORNET data. Revised QA and QC procedures and empirical correction schemes were constructed for use in a data assimilation quality product (Manuscript in preparation).

For the over land implementation, errors in MODIS retrieved aerosol optical depth relating to observation geometry, surface boundary conditions, snow and cloud contamination, and aerosol microphysical properties were described, quantified, and, to the extent possible with existing ancillary datasets, corrected. Several observation data sets were compiled for evaluation in the NAVDAS-AOD aerosol data assimilation system. Because appropriate snow and albedo data sets to complete filtering of AOD retrievals are not currently available in real-time, a climatological approach was developed and tested retrospectively.

We began the study of multi-sensor data fusion over both land and ocean using the operational MODIS, MODIS DeepBlue and MISR aerosol product and the newly develop aerosol assimilation product, NAVDAS-AOD.

Developed an observational aerosol climatology using one year of CALIPSO data. Included the observation based aerosol climatology in the newer version of NAVDAS-AOD.

As part of a future effort on scaling effects, we also began a study of sample biases and contextual biases in the over water MODIS aerosol product. A manuscript is in preparation.

Staged and performed initial analysis of non-biomass burning organic and black carbon to complete NAAPS's primary species inventory.

RESULTS

This project encompasses a number of sub projects. Key results are as follows:

Collection 5 over ocean data quality study: The quality of collection 5 (C5) MODIS over water product was studied for its use in aerosol data assimilation. Three years of MODIS C5 over water aerosol data were collocated and intercomared with ground based observations as functions of low boundary condition, aerosol optical properties, and cloud contaminations. Uncertainties in the MODIS data were examined, and the procedures in constructing a data-assimilation quality product were developed, which include quality assurance procedures and empirical correction steps. One of the major finding of this study is that despite assurances from original developers, large discrepancies are found between the collection 5 aerosol fine mode fraction (η) and both collection 4 and AERONET derived aerosol fine mode fractions. This large discrepancy in η, if not carefully categorized, could have adverse impact our data assimilation studies, and will significantly hamper research efforts that use the MODIS aerosol fine mode fraction for anthropogenic aerosol climate studies. Using multi-channel aerosol optical depth (AOD) retrievals from MODIS, we reconstructed η based on a spectral-deconvolution method [O'Neill et al., 2001]. We expect to transition this new data assimilation quality MODIS correction 5 over water product to a 6.4 prototype assimilation system by the coming fiscal year.

Collection 5 over land data quality study: MODIS retrieved AOD data were compared with AERONET data to evaluate errors and uncertainties. MODIS Collection 5 AOD is greatly improved from Collection 4, with 40% lower RMS error vs. AERONET. By identifying and filtering retrievals with problematic observation geometry, atmospheric conditions, and surface boundary conditions, we were able to reduce the RMS error by a further 25%, to levels approaching those of the assimilation-quality over-ocean product.

Multi sensor data fusion: Advanced satellite aerosol optical depth retrievals and datasets now allow the scientific community an unprecedented volume of observations of the global aerosol distribution. Each algorithm has advantages and disadvantages, and no single dataset can boast top performance everywhere over the globe. We developed a multi-sensor aerosol optical depth analysis over Saharan regions by assimilating MODIS operational, MODIS deep blue, and MISR aerosol products into NAAPS via NAVDAS-AOD for June to August, 2005. Our study suggested that aerosol data assimilation can be a very efficient technique for multi-sensor aerosol data fusion. Our study also suggested that aerosol and aerosol modeling could in turn greatly benefit from the multi-sensor aerosol observations. A more than 50% increase is found for the correlation between NAAPS and AERONET aerosol optical depth (including both land and ocean) after assimilating data from multi-sensor measurements into NAAPS (Figure 1).

Contextual and clear sky bias: The spatial distribution of aerosol optical properties derived from satellite observations are limited by various sampling biases including biases introduced by sampling methods, clear sky biases, and retrieval method introduced sampling biases. Using one year of NAAPS Aerosol Optical Depth (AOD) product with assimilation, we estimated the sampling biases in the operational MODIS level 2 collection 5 over water aerosol products. Our main conclusions were that although global mean AOD over global oceans show a small sampling bias, large regional biases (both negative and positive) are found even for three month averages. The averaged negative and positive sampling biases are found to be on the order of 10%, and should be aware for any regional studies.

This study suggests that at least two weeks of MODIS data are required for a reasonable coverage of aerosol field over global oceans. Adding two sensors (Both Terra and Aqua) would not significantly improve sampling biases.

This study also suggests that the Indo-China region has consistent positive sampling bias for all seasons. And other major areas with positive sampling biases are ITCZ, and high latitude regions over both Northern and Southern hemisphere that are associated with high cloud fractions. Major areas with negative sampling biases are found over the coast of South America and west coast of Africa that could associated with contextual biases.

CALIPSO climatology: One of the limitations in the 2-D var version of aerosol assimilation is that NAAPS aerosol climatology was used in redistributing the analysis increments from 2-D aerosol optical depth fields to 3-D aerosol mass concentrations. A new CALIPSO climatology is included in the NAVDAS-AOD for a better representation of the aerosol vertical distributions in NAAPS. The CALIPSO climatology is constructed for four seasons, four aerosol types (smoke, dust, sulfate, and seal salt), with spatial and vertical resolution of 5°Lat/Lon, and 250m-2km (vary with altitude) respectively. However, insignificant improvements were found in the NAAPS analysis (mostly over small AOD values), and a 3-D var data assimilation package may be necessary for NAAPS to fully benefit from the CALIPSO measurements.

Anthropogenic organic and black carbon: the NAAPS model carries only ammonium sulfate as a representation of pollution. While this was considered acceptable when NAAPS was first constructed, it is now well understood that anthropogenic sources of black and organic carbon from biofuel and industry can account for more than half of the pollution loads in east and southern Asia. An initial source function has been staged (Figure 2), which will provide significant improvements to NAAPS once the species are included (to be complete in FY09), particular in the Pakistan, India, SE Asia, and China.

IMPACT/APPLICATIONS

The AOD datasets were have produced will allow us to directly test the forecast impact of different choices balancing aggressive data filtering with avoiding unnecessary reduction in data volume and coverage. Once the tradeoffs have been quantified, we can begin to incorporate over-land AOD observations in the NAVDAS-AOD system, thereby improving forecast skill over both land and ocean. Once fully implemented, it will be considerably easier to add additional sensors and sustain long term support of the system. Further, with the substantially improved model efficacy data assimilation provides, it will be possible to predict higher level radiation fields and EO propagation in both the global, and eventually mesoscale models.

TRANSITIONS

Code for optical depth data assimilation and NAVDAS-AOD has been delivered to FNMOC for implementation. The algorithm for constructing a data assimilation quality MODIS collection 4 over water product has been delivered as well.

RELATED PROJECTS

This project is tightly coupled to a number of ONR 32 programs, including Large Scale Aerosol Modeling Development (PI: Doug Westphal), and COAMPS-On Scene (PI: John Cook). We have also begun working with Jim Hansen on his ONR 32 grant on the use of ensemble data assimilation for the prediction of atmospheric constituents.

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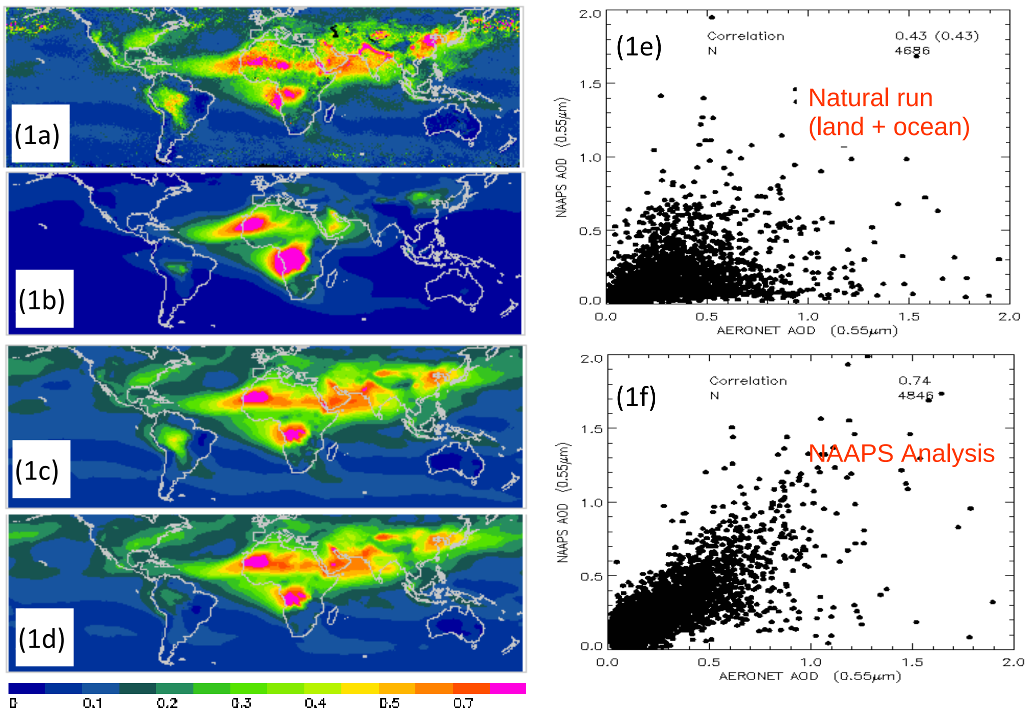

AOD at 0.55µm

Figure 1a. Three month average of MODIS operational, MODIS DeepBlue and MISR aerosol products for June-August, 2005. 1b) NAAPS AOD forecast for the same study season as Figure 1a. 1c) NAAPS analysis with the inclusion of MODIS operational, MODIS DeepBlue and MISR aerosol products for the same study period as Figure 1a. 1d) Simiar to Figure 1c, but for 6 hour forecast. 1e) intercomarision of NAAPS and AERONET AOD for NAAPS run without data assimilation for the same study period as Figure 1a. 1f) Similar to Figure 1e but for NAAPS runs with assimilation of the three satellite products as shown in Figure 1c.

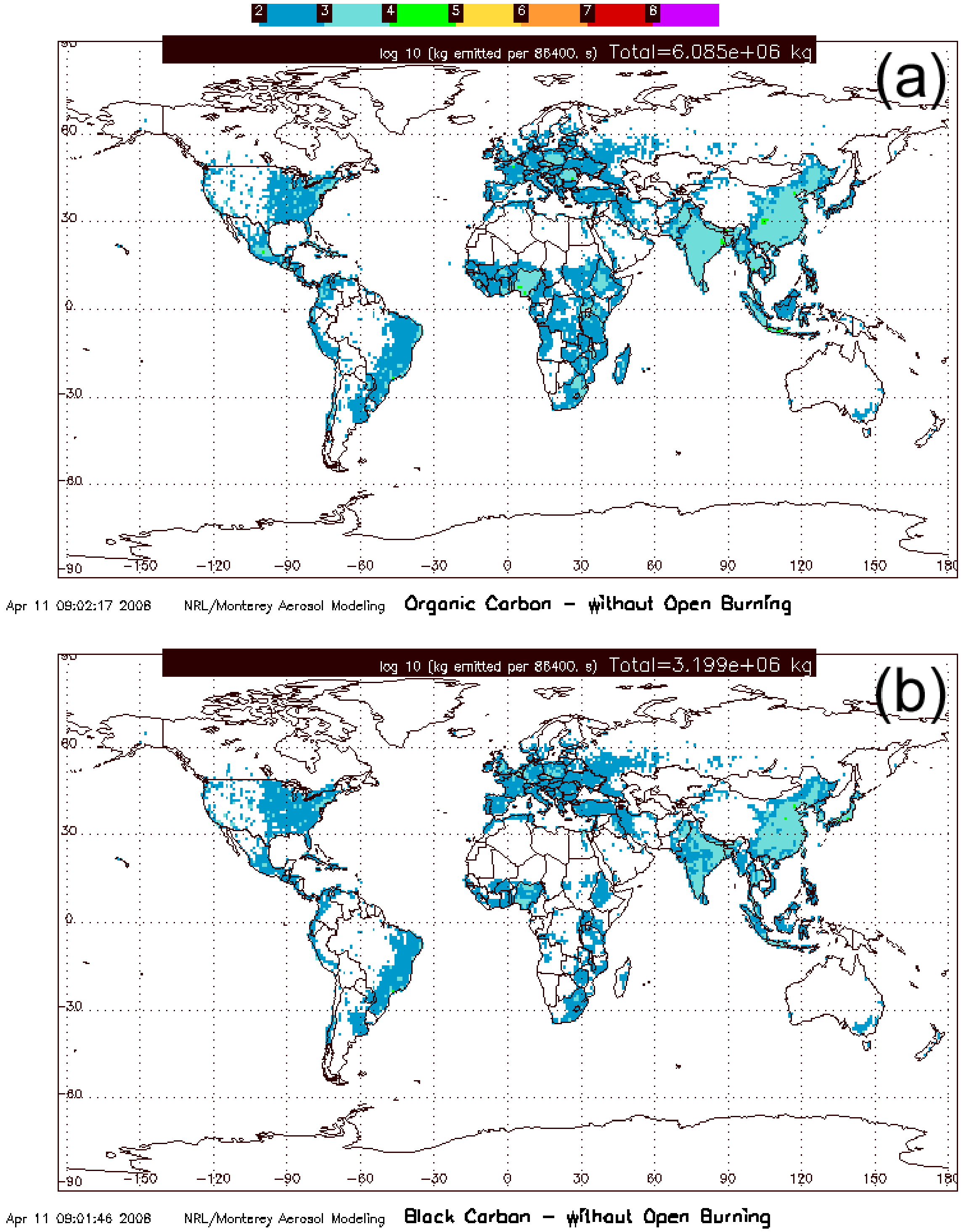

Figure 2: Anthropogenic organic (a) and black carbon (b) emissions (excluding open burning) staged for use in NAAPS based on the inventory of Bond et al., [2004].